

URBAN MORPHOLOGY AND GENERATIVE PROCESSES: CORE PRINCIPLES OF CONTEMPORARY CITY PLANNING

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ABSTRACT

Urban development unfolds through both planned interventions and spontaneous, self-organizing processes. Understanding the dynamic interplay between these forces is central to contemporary urban theory and practice. This paper explores how integrating traditional, form-based approaches to urban morphology with complexity-informed, generative models can enhance our ability to design cities that are adaptive, inclusive, and experientially rich.

Drawing on a review of key morphological frameworks - historical-geographic, typological, and spatial-analytical - we identify how each contributes to understanding urban form, while also highlighting their limitations in addressing contemporary challenges such as climate change, technological disruption, and socio-spatial fragmentation. We argue that the generative process, when embedded within cultural and regulatory norms, offers a productive paradigm for shaping resilient urban environments.

The paper further examines how simulation technologies - including agent-based modelling, cellular automata, and GIS-integrated analysis - enable planners to engage with urban complexity at multiple scales. These tools not only model emergent spatial patterns but also support the design of environments attuned to human behavior, interaction, and perception. The case of the Vauban district in Freiburg illustrates how such approaches, when combined with participatory planning, can produce ecologically responsible and socially cohesive urban forms.

Ultimately, we propose that the future of urban design lies in bridging formal spatial analysis with lived experience. In this context, the concept of the "liquid city" offers a generative framework for envisioning urbanism as an evolving, negotiated process - one that prioritizes flexibility, relationality, and human-centered values.

KEYWORDS _ *urban morphology, generative models, complexity, livability, inclusiveness*

INTRODUCTION

The richness and diversity of human settlements - and the enduring effort to understand their origins and evolution - have long captivated scholars. However, only after the Industrial Revolution did large-scale, sustained interventions in their structure and function become feasible. Before this shift, city planning was primarily concerned with refining the physical form, often seen more as artistic composition than socio-economic system. The 20th century brought a proliferation of urban theories, expanding the discourse beyond traditional planning. Concepts of urban form and function permeated disciplines ranging from art and the humanities to engineering and, more recently, physics. Today, architects and planners face new challenges shaped by rapid technological change, environmental urgency, and evolving societal expectations.

URBAN MORPHOLOGY AND DIFFERENT APPROACHES TO ITS RESEARCH

Just as human settlements are inherently multifaceted, so too are the approaches used to interpret them. Urban research spans a wide array of disciplinary lenses - ranging from social, economic, and ecological, to statistical, spatial-geographic, formal, historical, psychological, informational, and aesthetic dimensions. Even within individual disciplines, multiple frameworks often emerge to address similar foundational questions. As Kropf (2009) notes, this multiplicity is particularly evident in morphological studies.

The predominance of form within the study of urban morphology largely derives from the fact that most representations of human settlements focus primarily on their physical configuration. Even when other dimensions - such as cadastral boundaries or administrative overlays - are included, they ultimately anchor themselves to the city's physical fabric. While this may appear self-evident and scarcely worth restating, it is precisely the tangibility, ubiquity, and durability of the physical dimension that render it the most effective reference point for coordinating and comparing the diverse aspects of urban morphology (Kropf, 2009).

Efforts to distill the immense diversity of urban morphologies into simplified, formal models for analytical purposes reached a peak during the 1970s and 1980s, culminating in the development of a range of historically and regionally distinctive 'city models' (Ehlers, 2011). These models, rooted in the historical and cultural particularities of specific urban centers, were embraced as expressions of cultural diversity in an increasingly globalized world. They functioned as abstract, idealized interpretations of traditional urban fabrics, each encapsulating spatial logics shaped by unique cultural narratives, historical trajectories, and ideological frameworks.

However, the accelerating pace of urban expansion and the growing hybridization of urban functions - driven by shifting socio-economic dynamics - have gradually eroded the foundations of these simplified typologies. The clarity and coherence once attributed to such models have been superseded by the complex, often fragmented realities of contemporary urban development. Today, traditional and culturally distinctive urban forms are largely confined to the historical cores of cities, while newer urban areas reflect a much more heterogeneous, adaptive, and transitory character.

The consideration of urban models inevitably prompts a series of fundamental questions. Foremost among them: *What do these categorized urban forms truly reveal about the essence and meaning of the city, and does this mode of understanding retain its relevance in the contemporary context?* Furthermore, *to what extent - and through which mechanisms - do global urbanization processes influence the formation, transformation, or erosion of traditional and culturally distinctive urban landscapes?* Most critically, we are left to ask: *Is it still possible to conceive new city models, and if so, by what principles and methods might such models be developed?*

Even when attention is limited to the physical form - arguably the most evident aspect of urban morphology - the complexity of analysis remains significant. Various methodological approaches

emphasize different characteristics of form, each shaped by distinct research aims. As Oliveira et al. (2014) point out, addressing urban form today often requires a combination of methods: morphological regionalization to map urban landscape units; comparative studies across different contexts; integrated classification systems uniting diverse morphological techniques; and hybrid approaches that merge Conzenian analysis with space syntax and GIS tools. These combinations aim to capture the dynamic and layered nature of urban form, particularly in evolving and suburban contexts. They also reflect an ongoing effort to reconcile traditional morphological theories with contemporary urban challenges.

By reflecting on these research approaches, and aiming to more explicitly establish the aspects included in different approaches to urban morphology, Kropf (Kropf, 2009) identifies four distinct approaches, each with a slightly different perspective on urban form: historical-geographical, configurational (space syntax), process-typological, and spatial-analytical:

- The historical-geographical approach, rooted in the work of M.R.G. Conzen, explains urban form through the temporal development of five key elements: location, function, urban landscape, socio-economic context, and evolution. Socio-economic context is seen as the interplay of diverse activities within a broader urban dynamic.
- The configurational approach, developed by Bill Hillier and Julienne Hanson through space syntax theory, focuses on the spatial structure of cities in relation to movement. It centers on the analysis of voids - particularly street networks - as the primary framework for understanding urban form. This approach encompasses four aspects: spatial representation, network analysis of the urban fabric, examination of functional patterns (movement, land use, segregation, migration), and interpretation of links between spatial configuration and social, economic, and cognitive dynamics.
- The process-typological approach, developed by Caniggia and Maffei, views urban form as a product of cultural processes over time. It considers five key aspects: physical form, function, conceptual idea of form, construction/modification, and cultural evolution. Built form emerges from shared experiences and local traditions, meaning that design and transformation are not isolated acts, but integral parts of an ongoing cultural and typological process shaped by context, relationships, and continuity.
- The spatial-analytical approach, exemplified by Michael Batty's work, views the city as a complex system shaped by local generative processes that give rise to global structure. Unlike more formalistic models, this approach applies concepts of emergence and evolution to understand urban dynamics. Urban models typically represent land parcels or their aggregations, emphasizing spatial interaction and transformation over time. Batty describes the city as a "problem of organized complexity," while also acknowledging the ambiguity surrounding definitions of form and function—an issue addressed later in the text.

GENERATIVE PROCESS AND CITIES AS COMPLEX ADAPTIVE SYSTEMS

Although numerous studies address the generative process, a universally accepted definition remains elusive. Nguyen (Nguyen, 2015) suggests that the generative process implies "incremental development goals to produce a coherently built environment based on feedback and continuing refinement". The author further states that the generative process refers to "sequential development, setting priorities for steps in growth, and the continuing improvement of settlements based on collaborative work," and illustrates this with a simple example of a generative system in action. In this system, urban forms emerge from a "negotiation" between local norms (local specificities of the built environment) on one side and proscriptive (restrictive) and prescriptive (stimulative) rules, i.e., laws, on the other (Figure 1).

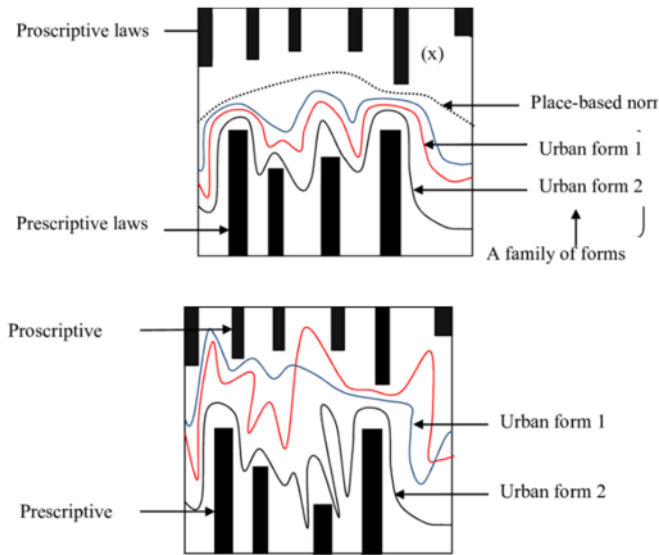


Figure 1: The diagrams (from Nguyen, 2015) illustrate cases where cities developed with norms (upper diagram) and without them, which would be a hypothetical scenario (lower diagram). In the first case, we have both proscriptive and prescriptive rules that are further limited by norms. The result is a variety of forms with distinct but unified qualities. Without norms, no family of forms can emerge; only a chaotic environment develops, even in the presence of regulations. Nguyen draws an important conclusion: norms are the foundation of any generative process, and rules devoid of norms are meaningless, even harmful. An example is computer-generated generative rules that, in the absence of cultural and social values, produce interesting urban forms, but also potentially alienating ones. Therefore, it is crucial to embed patterns and properties that carry cultural and social values when encoding generative processes.

The study of complex systems has long engaged scientists seeking to understand dynamic, interconnected phenomena. Meyers (Meyers, 2009) defines them as “systems that comprise many interacting parts with the ability to generate a new quality of collective behaviour through self-organization, e. g. the spontaneous formation of temporal, spatial or functional structures. They are therefore adaptive as they evolve and may contain self-driving feedback loops. Thus, complex systems are much more than a sum of their parts. Complex systems are often characterized as having extreme sensitivity to initial conditions as well as emergent behaviour that are not readily predictable or even completely deterministic.” Batty (Batty, 2011) echoes this view, citing Jeff Johnson’s explanation to be the best definition, describing them as “systems that have the potential to reconfigure themselves in ways that can be surprising.” He further argues (Batty, 2005), cities are the greatest examples of complex systems, appearing as a product of natural processes and growing bottom up, when observed using the complexity theory. Within this framework, urban systems are no longer seen as merely complicated, but truly complex, due to the inherent unpredictability and openness of generative, bottom-up development.

Complexity theory, particularly through Otto Frei’s analysis of urban patterns (Lopes et al., 2014), has enhanced our ability to understand, trace, and simulate the self-organizing mechanisms of cities. Informal phenomena such as “cow paths” and unplanned urban patterns reveal underlying logic and hidden rules that guide spontaneous urban growth. With the advent of digital technologies, Frei’s approach was extended, enabling more nuanced studies of urban form and process. This evolution found broad application in parametricism, an architectural movement developed to address increasingly complex urban conditions through the integration of functional and aesthetic complexities (Figure 2).

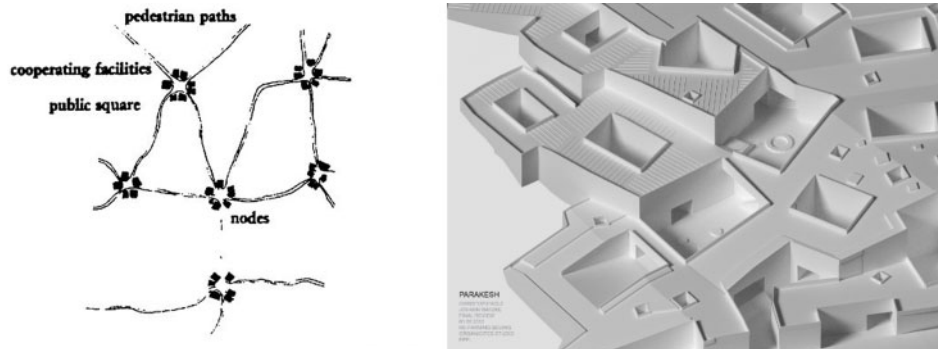


Figure 2: Left: Movement patterns have diagrammatic and verbal descriptions, and codify the built environment, allowing it to be recreated. People feel more comfortable in organic environments shaped over time, as opposed to sterile, unequivocally designed urban environments (source: Alexander, 1977). Right: Project Parakesh - an example of a city based on movement patterns, which cannot be designed without digital and information technologies ("negotiation" with maps and hydrological data, calculation of visual expression based on specified parameters). The final result of the city is undeniably reminiscent of organically formed Saharan cities (from Holz and Watzke, 2012).

Globalization - through economic recession, intensified migration, ecological crises, and multiculturalism - has created pressure to restructure urban and spatial systems. This manifests in growing demands on the social and physical fabric of cities, often prompting large-scale urban development projects. Today, over fifty megacities - urban areas with populations exceeding ten million - exist as both products and drivers of globalization. Their rapid growth presents complex administrative, political, economic, social, and ecological challenges. Crucially, it is increasingly argued that cities, rather than nation-states, have become the central actors in globalization, undergoing drastic morphological and functional transformations. These changes are not solely due to population growth, but also stem from rising intercity competition. As Janoschka (2019) notes, megacities embody global processes, influencing governance, sustainability, and the formation of new, intricate social dynamics. These evolving urban systems - and the broader regions they influence - are a central focus of Michael Batty's research on complexity and urban form.

Batty's application of complexity theory to urban dynamics (Batty, 2005) produces models that integrate numerous urban processes into organic, evolving urban forms. He proposes combining these processes with bottom-up geometries, using fractal patterns and chaotic dynamics to build applicable theories for highly complex urban systems. A central tool in his work is cellular automata (CA), which simulate urban growth based on localized interactions. In CA models, space is represented as a grid of cells (e.g., a topographic map), each with a set of possible states. The state of each cell evolves in response to the states of its neighbouring cells, typically defined as the eight immediately surrounding it in a square grid. This method captures the emergent behaviour of urban systems through simple, rule-based local interactions.

Batty then introduces agent-based models (ABM) - a powerful simulation technique in which autonomous agents move through space and interact according to predefined behavioural rules. These models operate across multiple scales, from street-level dynamics to regional urban structures (Figure 3, left). Batty applies ABMs to real urban contexts, incorporating concepts such as criticality, thresholds, novelty, surprises, and phase transitions to better understand spatial development. Each agent within an ABM represents an individual actor with unique behaviour, interacting with both the environment and other agents. With advances in computational power and data availability, ABMs have become a key paradigm in urban modelling - capable of simulating everything from pedestrian movement over seconds to urban expansion over decades. These models range from abstract simulations to geospatially grounded environments, allowing for calibration and validation through generated scenarios and real-world data.

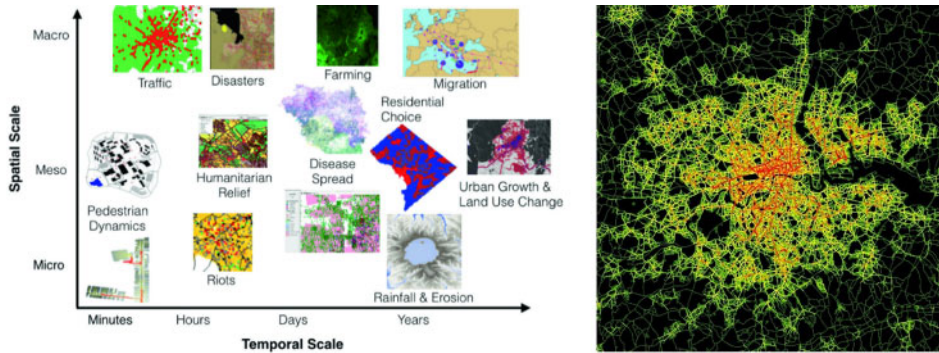


Figure 3: Left: Models created using the MASON toolkit and its GeoMason extension for GIS integration encompass both spatial and temporal scales (source: Crooks et al., 2021). They allow for simulating processes ranging from the micro-movements of pedestrians over a few seconds to the macro-movements of migrants over the years. Right: An example of fractal-based modelling: streets of Greater London classified by traffic volume (source: Batty, 2013)

In Batty's urban modeling, fractals (Figure 3, right) are structures that exhibit self-similarity - their properties remain consistent across changes in scale, whether spatial (from districts to regions), temporal (from minutes to years), or thematic (e.g., land use at varying levels of detail). This fractal quality means that zooming in or out reveals patterns that resemble one another, regardless of the level of observation. In the urban context, fractals primarily relate to morphology, highlighting how city form emerges from the interaction between location and spatial structure. These patterns reflect the interconnected nature of urban elements, and the processes generating fractals closely resemble those of cellular automata, relying on simple, repeated rules to produce complex, layered forms. As noted in the spatial-analytical approach, there is a purposeful blurring between the physical form of the city and its functional use. Batty emphasizes that urban models are not intended to be precise or predictive, but rather to "strip down the processes of city development to their most basic elements, and thus to reveal the fundamental mechanisms at work" (Kropf, 2009). However, he also highlights the suggestive potential of simplified models of traditional urban forms, which can serve as generative modules (Batty, 2013). This idea resonates with the growing interest in modular urban planning, a strategy increasingly adopted in practice - often as a response to crises and the shortage of qualified professionals. Rooted in concepts from computer science, this approach relies on semi-automated generation of urban fabric through generative planning, capable of adapting to a range of contextual and boundary conditions.

The application of technologies such as ABM, CA, and complexity theory offers more than analytical precision - they introduce a paradigm shift in how urban environments can be conceived, experienced, and designed. These models simulate not just spatial growth, but the behavioral dynamics of urban actors across multiple scales and timeframes. Their strength lies in the capacity to capture emergent phenomena arising from localized interactions, making it possible to anticipate how individuals navigate, perceive, and inhabit urban space. From this perspective, generative modelling becomes a means of designing with - not merely for - users. ABM and CA frameworks allow planners to explore scenarios of everyday use: how people move, congregate, avoid, or adapt to spatial conditions, and how minor changes in design (e.g., street width, lighting, or access points) can impact comfort, safety, or social interaction. When enriched with participatory data and context-specific norms, these models foster the development of inclusive, adaptable, and perceptually coherent environments. Moreover, complexity-informed design enables responsiveness to diverse user needs, including those of vulnerable populations, by acknowledging that urban life is not uniform, but layered and situational. In this way, technologically driven approaches do not oppose human-centered design; rather, they enhance it - serving as tools for translating behavioral insight and sensory experience into spatial logic. Ultimately, such integration affirms a core principle of contemporary urbanism: that successful environments are those shaped as much by their adaptability and relationality as by their form.

CONCLUSIONS

Formal approaches to urban morphology - particularly historical-geographic, typological, and spatial-analytical models - remain instrumental in elucidating the spatial organization and functional hierarchies of urban systems. However, considering the increasing complexity, fluidity, and hybridization of contemporary cities, these frameworks alone are no longer sufficient. A more comprehensive understanding requires their integration with generative models grounded in complexity theory and emergent behavior.

Advances in simulation technologies - such as agent-based modelling, cellular automata, and GIS-integrated analysis - offer powerful tools for modelling urban growth and adaptive patterns. These methods not only enhance predictive capacity but also support the design of environments responsive to change and attuned to diverse user needs. When applied critically, they enable spatial strategies that foster livability, inclusiveness, and experiential depth. The Vauban district in Freiburg exemplifies this potential: developed through participatory planning and feedback-informed simulations, it integrates ecological sustainability with social and spatial cohesion. Its car-free design, inclusive public spaces, and housing cooperatives promote everyday livability and diversity. By supporting interaction, walkability, and a sense of belonging, Vauban shows how generative models, when rooted in cultural and behavioral contexts, can yield inclusive, human-centered urban forms.

The future of urban theory and practice lies in bridging systemic complexity with lived experience. As urbanization increasingly unfolds through decentralized, non-linear, and relational dynamics, the models we adopt must address not only spatial structure but also perception, identity, and human agency. This calls for a shift - from cities as designed objects to cities as evolving, negotiated processes. In this light, John Rennie Short's notion of the "liquid city" becomes more than metaphor: it serves as a conceptual imperative, urging us to envision urban form as adaptive, porous, and open to redefinition - shaped as much by cultural flows, affective geographies, and everyday practices as by rules, codes, and physical infrastructure.

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